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## **Current trends in vena cava reconstructive techniques with major liver resection: a systematic review**

Baimas-George, Maria ; Tschuor, Christoph ; Watson, Michael ; Sulzer, Jesse ; Salibi, Patrick ; Iannitti, David ; Martinie, John B ; Baker, Erin ; Clavien, Pierre-Alain ; Vrochides, Dionisios

**Abstract:** Purpose: Historically, invasion of the inferior vena cava (IVC) represented advanced and often unresectable hepatic disease. With surgical and anesthetic innovations, IVC resection and reconstruction have become feasible in selected patients. This review assesses technical variations in reconstructive techniques and post-operative management. Methods: A comprehensive literature search was performed according to PRISMA. Inclusion criteria were (i) peer-reviewed articles in English; (ii) at least three cases; (iii) hepatic IVC resection and reconstruction (January 2015-March 2020). Primary outcomes were reconstructive technique, anti-thrombotic regimen, post-operative IVC patency, and infection. Secondary outcomes included post-operative complications and malignant disease survival. Results: Fourteen articles were included allowing for investigation of 351 individual patients. Analysis demonstrated significant heterogeneity in surgical reconstructive technique, anti-thrombotic management, and post-operative monitoring of patency. There was increased utilization of ex vivo approaches and decreased use of venovenous bypass compared with previously published reviews. Conclusion: This review of literature published between 2015 and 2020 reveals persistent heterogeneity of hepatic IVC reconstructive techniques and peri-operative management. Increased utilization of ex vivo approaches and decreased use of venovenous bypass point towards improved operative techniques, peri-operative management, and anesthesia. In order to gain evidence for consensus on management, a registry would be beneficial.

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# Current trends in vena cava reconstructive techniques with major liver resection: a systematic review

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## Abstract

**Purpose** Historically, invasion of the inferior vena cava (IVC) represented advanced and often unresectable hepatic disease. With surgical and anesthetic innovations, IVC resection and reconstruction have become feasible in selected patients. This review assesses technical variations in reconstructive techniques and post-operative management.

**Methods** A comprehensive literature search was performed according to PRISMA. Inclusion criteria were (i) peer-reviewed articles in English; (ii) at least three cases; (iii) hepatic IVC resection and reconstruction (January 2015–March 2020). Primary outcomes were reconstructive technique, anti-thrombotic regimen, post-operative IVC patency, and infection. Secondary outcomes included post-operative complications and malignant disease survival.

**Results** Fourteen articles were included allowing for investigation of 351 individual patients. Analysis demonstrated significant heterogeneity in surgical reconstructive technique, anti-thrombotic management, and post-operative monitoring of patency. There was increased utilization of ex vivo approaches and decreased use of venovenous bypass compared with previously published reviews.

**Conclusion** This review of literature published between 2015 and 2020 reveals persistent heterogeneity of hepatic IVC reconstructive techniques and peri-operative management. Increased utilization of ex vivo approaches and decreased use of venovenous bypass point towards improved operative techniques, peri-operative management, and anesthesia. In order to gain evidence for consensus on management, a registry would be beneficial.

**Keywords** IVC resection · Reconstruction · Hepatic disease · Malignancy · Patency · Systematic review

## Introduction

Historically, involvement of the inferior vena cava (IVC) by hepatic tumor represented advanced, unresectable disease. With venous invasion being relatively uncommon, the true incidence has yet to be described; however, it is clearly associated with a poor prognosis [1]. Further, there is typically a poor response to chemotherapy or medical treatment, such that surgery often offers the only option for improved survival

[2, 3]. Thus, beginning in the 1990s and the piggybacking off techniques used with leiomyosarcoma, case reports and series began to emerge demonstrating feasibility of IVC resection and reconstruction in select populations [4–11]. These developments continued to evolve with convergence of transplant techniques such as venovenous bypass, and total hepatic vascular exclusion, together with portal vein embolization and cardiopulmonary bypass [12, 13]. Further innovations such as ex vivo resections and advances in chemotherapy expanded the pool of potential surgical candidates [14]. Even with technical advances, associated surgical risk remains relatively high and long-term survival is often poor [11].

There continues to be a lack of literature on clinical outcomes of caval reconstructive replacement with the majority of published reports being single-cases or small case series. As such, the type of IVC reconstructive technique widely varies among surgeons and centers [15]. Typically, it depends on tumor location, adherence, and circumferential venous

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involvement. Reconstructive options include primary repair, graft replacement, patch replacement, and if adequate collateral circulation is present may even permit ligation [10]. Once modality of repair is decided, controversy still exists over conduit material with an amalgam available including autologous vein, cadaveric donor allograft, and various synthetics. The most widely used prosthesis tends to be the readily available ringed PTFE graft due to strength and size variety allowing for diameter congruency [8, 10, 16]. Recently, cardiothoracic data suggests venous biological grafts may be superior to PTFE due to improved long-term patency and decreased infection risk although this data is not specific on IVC reconstruction [17, 18]. In transplant programs, a preferred material has been the use of preserved organ donor iliac veins which unfortunately is not allowed in the USA under current United Network for Organ Sharing (UNOS) guidance outside of the transplant setting [19–21].

There is a paucity of data assessing post-operative morbidity by type and material of IVC reconstruction and no general consensus on use and duration of anti-thrombotic therapy. While good long-term patency has been demonstrated without intraoperative or post-operative anti-thrombotics due to high IVC flow rates, others report the necessity of long-term therapy with synthetic graft repair [1, 3, 16, 22–24]. Moreover, many studies lack descriptions of post-operative patency monitoring protocols or only obtain imaging if clinical concern [16]. Infection, although rare, is another concern, particularly with synthetic grafts with some surgeons advocating omental interposition techniques [4, 5, 24, 25]. Long-

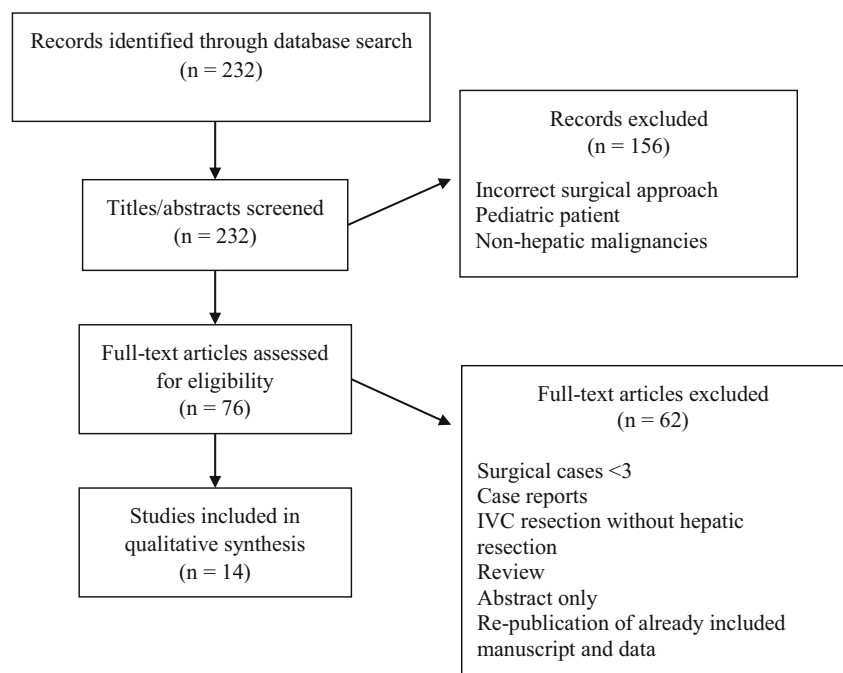
term outcomes vary with data on retroperitoneal tumors suggesting a survival difference between IVC primary or patch repair with circumferential resection [16].

There have been two recent comprehensive reviews evaluating articles up to 2015 and to 2016, assessing the safety and efficacy of IVC reconstruction during hepatic resection [26, 27]. These demonstrate a wide variety in technique and management including use of anti-thrombotic guidelines and routine assessment of post-operative patency. With IVC resection continuing to be more frequently performed, we sought to conduct a systematic review of articles published between 2015 and 2020. Our aim was to assess current trends and evaluate the efficacy of technical variations in reconstructive techniques as well as post-operative management strategies to reduce morbidity, mortality, and improve long-term survival.

## Methods

A comprehensive literature search was performed by two independent researchers (MBG, DV) according to PRISMA guidelines using PubMed, Medline, and EMBASE databases in March of 2020 to investigate variance and outcomes by IVC reconstruction techniques (Fig. 1) [28]. The databases were searched with the Medical Subject Headings and keywords outlined in Table 4 in Appendix 1. Titles were screened and abstracts were reviewed for relevance. Relevant abstracts were read in their entirety. Inclusion criteria for eligibility

**Fig. 1** Comprehensive literature search according to PRISMA guidelines



were (i) peer-reviewed articles in English; (ii) at least three patient cases described; (iii) studies including hepatic IVC resection and reconstruction published between January 01, 2015, and March 10, 2020. Case reports were excluded as were cases of IVC resection without concurrent hepatectomy. Studies that included cases not meeting criteria for the systemic review were not included if the outcomes were not separated and differentiated from the outcomes of cases with IVC resections.

Two reviewers independently identified and extracted data from the studies included in this systematic review in which they were blinded to each other's process. Data abstraction included study characteristics (author, year of publication etc.), patient demographics and disease characteristics, operative details, and outcomes measured. The primary outcomes were IVC reconstructive technique, anti-thrombotic regimen, and post-operative venous patency and infection. Secondary outcomes included post-operative complications and survival (1-, 3-, and 5- year survival).

The methodological quality for the included trials was assessed independently by two reviewers based on the Newcastle-Ottawa scale [29]. Due to the significant heterogeneity observed among studies in terms of patient characteristics and surgical details, meta-analysis was not performed.

## Results

### Literature review

The results of the search conducted in accordance with PRSIMA guidelines are presented in Fig. 1. The initial search resulted in 232 eligible articles. All of these titles and abstracts were screened for relevance. Reasons for exclusion included transplantation cases, pediatric patients or resections without hepatic involvement. There were 76 articles that subsequently underwent full text review and detailed evaluation. Of these, 62 articles were excluded with the majority being either case reports, case series with less than three cases, or review articles. Three articles were excluded as the outcomes from the venous resection group were not differentiated from the other populations [30–32]. One article was omitted due to duplicate data [33]. This resulted in 14 articles included in the final qualitative synthesis [14, 34–46]. All 14 articles were case series and thus uncontrolled-observational trials. The risk of bias assessment with the Newcastle-Ottawa Scale was assessed by two reviewers [29]. As all studies had no control groups, they were scored four points out of seven which is considered to be of poor quality due to missing control.

### Study population and surgical characteristics

Patient demographics and primary disease processes are outlined in Table 1 and Table 5 Appendix 2. Several studies presented stratified data by diagnosis or operative technique and are represented accordingly in the tables [36, 41, 44, 46]. Of the 14-case series examined, there were 351 patients studied with ages ranging between 30 and 72 years of whom 34% were female. The most common hepatic diseases were hepatocellular carcinoma (HCC) (54%) and hepatic alveolar echinococcosis (HAE) (29%). Remaining diagnoses included intrahepatic cholangiocarcinoma (IHCC) (3%), colorectal liver metastases (CLM) (4%), adrenal carcinoma (1.4%), leiomyosarcoma (< 1%), and other diseases (1.4%).

Surgical resection approach and technique varied with reported data outlined in Table 1. Techniques involving resection under hypothermic perfusion include ante situm, in vivo, and ex vivo approaches. Cross-clamping of the major vessels with division of the suprahepatic IVC alone, conserving the hepatic artery and portal pedicle, describes the ante situm technique [47]. Similarly, in situ exposure cross-clamps the major vessels but does not transect the IVC. Lastly, the ex vivo approach divides all major vessels to allow for entire liver removal with resection on the backbench followed by autotransplantation [48]. Unfortunately, these procedures are limited by hepatic intolerance to warm ischemia, hemodynamic instability, and intestinal vasculature congestion [49]. In an attempt to ameliorate these complications, venovenous bypass and hypothermic hepatic perfusion are commonly used strategies [31, 43, 50]. Of the surveyed reports in this review, 20% of cases utilized an ex vivo approach; whereas only 3% performed an ante situm resection and 10% an in situ approach. Venovenous bypass was used to preserve hemodynamic stability in less than 2% of cases. Hepatic vein reimplantation was required in almost a quarter of patients and operative time and estimated blood loss varied quite extensively due to the significant heterogeneity between procedures and populations.

### IVC resection and reconstruction

IVC resection techniques varied between articles with details only described for 203 of 350 patients. About one-third of patients (32%) underwent a primary caval repair [35, 36, 39, 41–43, 45]. Two studies described ligation without repair which was only 7% of described cases [36, 44]. Forty percent of patients had synthetic graft replacement, typically with PTFE graft [14, 34, 35, 42, 43, 45, 46]. Autologous graft replacement was another described technique using either the saphenous vein or inferior mesenteric vein (IMV) for 17% of cases [36, 43]. Patch closure was only used in 3% of cases with either synthetic PTFE patches or an autologous vein patch with the IMV [34, 36, 39, 41, 43]. Three studies did not provide any detail on IVC resection and reconstruction [37, 38, 40].

**Table 1** Surgical resection technique and intraoperative details. *HCC* hepatocellular carcinoma, *CLM* colorectal liver metastases, *HAE* hepatic alveolar echinococcosis, *ACC* adrenocortical carcinoma, *IHCC* intrahepatic cholangiocarcinoma, *VVB* venous bypass, *THVE* total hepatic vascular exclusion. Values reported as No. (%), median (range), or average ( $\pm$  standard deviation)

Study	N	Diagnosis	Surgical resection	Ex vivo	Ante situm	In situ	VVB	Concomitant hepatic vein reconstruction	THVE
Ko et al. [39]	8	HCC (1) CLM (7)	Extended right hepatectomy (3) Right hepatectomy (2) Extended Anterior segmentectomy (1) Partial resection (2) Right hepatectomy (1) Extended right hepatectomy (3) Right trisectionectomy (7) Left trisectionectomy (2) Right hepatectomy (2) Extended right hepatectomy (2) Right trisectionectomy (13) Extended left hepatectomy (1) Left trisectionectomy (5)						8 (100)
Li et al. [46]	13	HCC without hepatic vein involvement (13)	Right hepatectomy (1) Extended right hepatectomy (3) Right trisectionectomy (7) Left trisectionectomy (2) Right hepatectomy (2) Extended right hepatectomy (2) Right trisectionectomy (13) Extended left hepatectomy (1) Left trisectionectomy (5)			0		0	0
Li et al.	23	HCC with hepatic vein involvement requiring PTFE or autologous vein patch (23)	Right hepatectomy (2) Extended right hepatectomy (2) Right trisectionectomy (13) Extended left hepatectomy (1) Left trisectionectomy (5)			8 (34.8)		23 (100)	3 (13)
Li et al.	6	HCC with hepatic vein involvement requiring artificial blood vessel (6)	Extended right hepatectomy (2) Right trisectionectomy (3) Left trisectionectomy (1)			4 (66.7)		6 (100)	6 (100)
Wen et al. [45]	15	HAE (15)	Extended right hepatectomy and autotransplantation (15) Right hepatectomy (2) Extended right hepatectomy (1) Extended left hepatectomy (1) Bisectionectomy or more extended resection (39)	15 (100)		0			
Ho et al. [37]	4	HCC (2), leiomyosarcoma (1), ACC (1)	Right hepatectomy (2) Extended right hepatectomy (1) Extended left hepatectomy (1) Bisectionectomy or more extended resection (39)	0					4 (100)
Kasai et al. [38]	39	HCC (39)	Right hepatectomy (3) Extended right hepatectomy (4) Right hepatectomy (1) Left hepatectomy (1) Mesohepatectomy (1) Partial resection (1) Left hepatectomy (1) Left trisectionectomy (1)	0	2 (5.1)	1 (2.6)			39 (100)
Vicente et al. [35]	4	CLM (2), HCC (2)	Right hepatectomy (3)	0	0	0	0	0	0 (0)
Lee et al. [42]	3	ACC (3)	Right hepatectomy (3)	0	0	0	2 (66.7)	0	
Oldhafer et al. [43]	8	IHCC (5), HCC (1), CLM (1), pheochromocytoma (1)	Right hepatectomy (3) Extended right hepatectomy (4) Right hepatectomy (1) Left hepatectomy (1) Mesohepatectomy (1) Partial resection (1) Left hepatectomy (1) Left trisectionectomy (1)	0	8 (100)	0	0	3 (37.5)	8 (100)
Baimas-George et al. [14]	3	CLM (1), leiomyosarcoma (1), IHCC (1)	Left hepatectomy (1) Left trisectionectomy (1)	3 (100)			3 (100)		

**Table 1** (continued)

Study	N	Diagnosis	Surgical resection	Ex vivo	Ante situm	In situ	VVB	Concomitant hepatic vein reconstruction	THVE
Chen et al. [40]		HCC with IVC thrombus (74)	Anatomical liver resection with en bloc thrombectomy						
Du et al. [44]	5	HAE (5)	Right hepatectomy (3)	0					
Du et al.	8	HAE with ex vivo approach (8)	Right trilobectomy (8) Left hepatectomy (1) Extended right hepatectomy (1)	8 (100)					
Shen et al. [36]	45	HAE–ex vivo approach (45)	Right trisectionectomy (42) Right hepatectomy (3)	45 (100)	0	0		45 (100)	
Shen et al.	26	HAE (26)	Right trisectionectomy (8) Right hepatectomy (13) Left trisectionectomy (3) Left hepatectomy (2)	0	2 (7.7)	24 (92.3)		6 (23.1)	
Tomimaru et al. [34]	12	IHCC (4), CLM (3), sarcoma (2), ACC (1), lymphoma (1), pseudotumor (1)	Right trisectionectomy (1) Right hepatectomy (4) Left hepatectomy (2) Posterior segmentectomy (2) Caudate resection (1) Partial resection (2) Major hepatectomy (9)						6 (50)
Matsukuma et al. [41]	16	HCC with type I IVC thrombus (16)	Major hepatectomy (9)				0		5
Matsukuma et al.	8	HCC with type II IVC thrombus (8)	Major hepatectomy (6)				0		5



## Anti-thrombotic regimen

The use and description of peri-operative and post-operative anti-thrombotics were not provided in a majority of examined studies. Three studies provided adequate detail: (1) prophylactic heparin 30 days post-operatively; (2) prophylactic low molecular weight heparin (LMWH) from post-operative day two until discharge; and (3) LMWH in hospital followed by coumadin at discharge for 90 days (Table 6 in Appendix 3) [35, 36, 46].

## Venous patency and infection

IVC patency was reported in 158 patients from nine of the 14 studies (Table 6 in Appendix 3). Venous occlusions were identified in 2.5% of cases, resulting in a 97.5% patency rate. Two studies found post-operative thromboses in the reconstructed IVC [35, 46]. Two studies found outflow stenosis with subsequent balloon dilatation for treatment [36, 42]. Only one study reported a reconstructed vessel infection; the remaining studies did not note any infections [46].

## Post-operative outcomes and long-term oncologic survival

Table 6 in Appendix 3 demonstrates follow-up and survival with all 14 studies reporting Clavien-Dindo major and minor complication rates [51]. Overall morbidity rate was 47.6% with the highest grade of complication reported minor in 19.8%

(Clavien-Dindo < 3) and major in 27.5% (Clavien-Dindo ≥ 3). There was a 30-day mortality rate of 3.1% (Table 2). Median survival in patients with malignant disease ranged between 12 and 36 months with disease-free survival ranging between 4 and 30 months. One-year overall survival was 67.2% (50–85%), reported in 245 patients. Three-year survival was 20.9% (0–34%), reported in 217 patients, and 5-year survival was 22.7% (0–30%), reported in 75 patients. Five-year survival was higher than 3-year survival as different studies were included due to variations in reporting overall survival.

## Discussion

This systematic review of literature examined 14 recent case series to evaluate technical approaches to IVC resection and reconstruction. The outcomes of 351 diverse patients were investigated and our assessment revealed a wide variety in surgical practice, anti-thrombotic management, and post-operative monitoring. As such, a consensus on best practice remains to be elucidated.

Due to anatomic proximity, primary and secondary hepatic tumors can invade the retrohepatic IVC, portending a poor prognosis [1, 52]. Even with advances in chemotherapy, resection for such advanced tumors is the only potentially curative therapy, offering up to 50% 5-year survival [53–55]. Previously, this was a contraindication to resection; however, considerable advancements made in conjunction with existing

**Table 2** Oncologic outcomes and long-term survival

Study	N	Mean follow-up (months)	Median survival (months)	Disease-free survival (months)	30-day mortality	1-year OS (%)	3-year OS (%)	5-year OS (%)
Ko et al. [39]	8		14 (8–60)		0 (0)	71.0		
Li et al. [46]	13		27.0	22.0	1 (7.7)*	84.6	23.1	
Li et al.	23		16.0	13.0	3 (13)*	78.3	8.7	
Li et al.	6		13.0	10.2	2 (33.3)*	83.3	0.0	
Wen et al. [45]	15	21.6 (6–43)			1			
Ho et al. [37]	4		12 (6–17)	8.5 (3–15)	0 (0)	50.0	0.0	0.0
Kasai et al. [38]	39		15.2	5.3	2 (5)	64.0	28.0	28.0
Vicente et al. [35]	4		36 (29–48)	29.5 (18–48)				
Lee et al. [42]	3		16 (6–42)	4 (4–42)	0 (0)	66.0	33.0	
Oldhafer et al. [43]	8		33.5 (0–107)	12 (0–107)	1	75.0		12.5
Baimas-George et al. [14]	3	12 (5–15)	12 (5–15)	12 (5–15)	0 (0)			
Chen et al. [40]	105		14.0	8.7	2	64.2	19.7	
Du et al. [44]	5	18.0 (17.0–35.0)						
Du et al.	8	20.0 (13.5–33.0)						
Shen et al. [36]	45	22 (6–66)			3*			
Shen et al.	28	22 (6–66)			3*			
Tomimaru et al. [34]	12	42.7 (19–90)			0 (0)	66.7		
Matsukuma et al. [41]	16		18.7		1*	61.0	34.0	17.0
Matsukuma et al.	8		12.6		0*	60.0	30.0	30.0

.OS overall survival. Values reported as No. (%), median (range), or average (± standard deviation)

\*90-day mortality

transplant surgical techniques have expanded technical options for vascular exclusion procedures and safe resection as well as reconstruction [13, 14, 56–58]. As these procedural constraints are overcome, the pool of eligible patients has widened, making liver resection in patients with IVC involvement increasingly common.

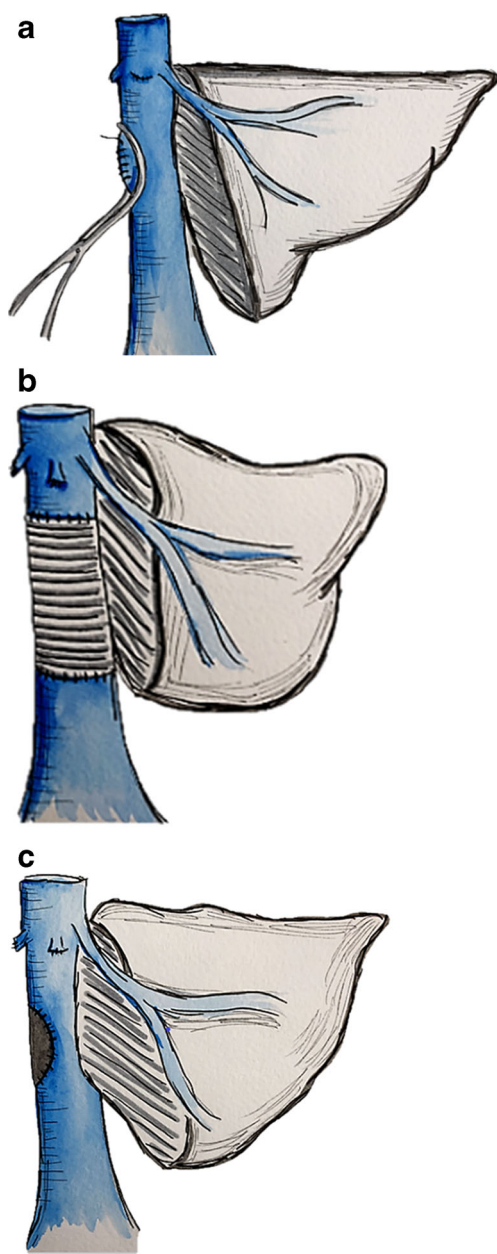
Depending on the extent of invasion, options for reconstruction vary and include primary repair, interposition graft, or patch angioplasty (Fig. 2) [59]. Ligation of the IVC can be appropriate if collateral circulation provides sufficient drainage and remains intact [60]. Tumor location and circumferential involvement usually dictate resection approach [27]. Currently, limited data with

low grade of evidence is available on tumors requiring hepatectomy with concomitant IVC resection and replacement in the form mainly of case reports or small case series. As such, there remains significant diversity present across and even within hospital systems on best approach.

In this study, we combined individual patient data in an attempt to elucidate a consensus on best practice for IVC resection and reconstruction in hepatic disease. Upon review and comprehensive analysis, that question remains unanswered because of the diverse population examined and the majority of studies did not discuss rationale to approach and conduit material preference. Synthetic graft replacement was the most common method of repair followed by simple suture repair. Autologous graft replacement was also relatively common with a variety of veins used as conduits. Post-operative thrombotic treatment was described in adequate detail in only three of the examined studies. Further, assessment and development for post-operative obstruction by thrombosis or stenosis were only reported in half of the reviewed studies. Of these 158 patients, four patients developed obstruction, resulting in an overall patency rate of 97.5%.

This systematic review assessed studies from the last half decade: January 2015 through March of 2020. In order to review trends and shifts in approach, we compared these results with two other comprehensive systematic reviews that assessed studies between 2000 and 2015 and between 1980 and 2016 (Table 3) [26, 27]. This demonstrated an upsurge in the total number of cases per year involving vena caval reconstruction, revealing a change in indication, particularly with more resections being attempted for aggressive HCC and extensive resections for hepatic alveolar echinococcosis (HAE) [61–64].

Variations in surgical technique demonstrate an increase in *e-vivo* approaches: 20% versus only 5% and 4% in the past two reviews. Thirteen percent of cases were performed via an *in situ* or *ante situm* approach versus 0% and 4% in the prior reviews, representing increasing dissemination of transplant techniques to hepatobiliary surgery [14]. Additionally, use of venovenous bypass was used in less than 2% of cases whereas previously, it was in 20 to 30% of cases. These shifts in approach may demonstrate a trend away from routine use of venovenous bypass with advancements in operative techniques, anesthesia, and peri-operative patient management [65, 66]. Increasing knowledge of physiology has eliminated it as the only option for augmenting preload, replaced by zealous use of vasopressors and volume, with the only true limiting factor requiring venovenous bypass being intestinal ischemia. Additionally, high complication rates as well as increased operative times and warm ischemia are associated with venovenous bypass; and the need for systemic heparinization, particularly in patients with liver disease and coagulation abnormalities, can have negative effects [67–71]. The concept of hypothermic perfusion without venovenous bypass and development of techniques to preserve caval flow have gained



**Fig. 2** Anatomical drawings of IVC reconstruction: **a** primary repair; **b** synthetic graft replacement; **c** patch closure



**Table 3** Comparisons between comprehensive analyses of IVC reconstruction systematic reviews

	Baimas-George et al. 2015 to 2020	Papamichail et al. 2000 to 2015	Zhou et al. 1980 to 2016
Preoperative characteristics			
<i>N</i>	351	238	258
Female (%)	119 (33.9)	100 (42)	133 (51.6)
Age	30–72	54	56.5 ± 12.3
Intrahepatic cholangiocarcinoma	10 (2.8)	62 (26)	51 (20)
Colorectal liver metastases	14 (4.0)	104 (43)	128 (50)
Hepatocellular carcinoma	191 (54.4)	45 (19)	48 (19)
Hepatic alveolar echinococcosis	101 (28.8)	0 (0)	0 (0)
Adrenal carcinoma	5 (1.4)	0 (0)	0 (0)
Leiomyosarcoma	2 (0.6)	10 (4)	0 (0)
Diagnosis: other	5 (1.4)	19 (7.9)	31 (11)
Surgical technique			
Ex vivo approach	71 (20.2)	12 (5.0)	10 (4.0)
Ante situm approach	12 (3.4)	0 (0.0)	11 (4.0)
In situ approach	36 (10.3)	0 (0.0)	0 (0.0)
Venovenous bypass	6 (1.7)	43 (19.8)	69 (29.0)
Concomitant hepatic vein reconstruction	83 (23.6)	19 (9.3)	15 (6.0)
IVC reconstruction			
Primary repair	65 (32.0)	86 (35.8)	115 (43.0)
Ligation without repair	15 (7.4)	0 (0.0)	3 (1.0)
Synthetic graft replacement	82 (40.4)	122 (50.8)	107 (42.0)
Autologous vein graft replacement	34 (16.7)	0 (0.0)	4 (2.0)
Homologous vein graft replacement	1 (0.5)	0 (0.0)	2 (1.0)
Synthetic patch closure	6 (3.0)	32 (13.3)	12 (5.0)
Autologous graft patch closure	0 (0.0)	0 (0.0)	8 (3.0)
Post-operative results			
R0 resection rate	92 (84.4)	181 (84.8)	—
Patency rate	154 (97.5)	116 (95.1)	258 (100.0)
Morbidity	167 (47.6)	74 (43.3)	101 (42.1)
30-day mortality	11 (3.1)	15 (6.25)*	14 (5.4)†
1-year OS	67.2%	78.1%	79%
3-year OS	20.9%	47.7%	45%
5-year OS	22.7%	40.0%	31%

.OS overall survival. Values reported as No. (%), median (range), or average (± standard deviation)

\*In-hospital mortality

† Post-operative complication mortality

momentum and demonstrate operative and/or post-operative advantage or equivalence [43, 72–75].

Methods for IVC reconstruction appear to remain stable over time with primary use of synthetic graft replacement or suture repair. In general, tumor location and circumferential involvement direct resection technique. Tangential resection with a primary simple suture repair can be used if tumor involves less than 25% of the vein circumference [76]. For tumor adherence between 25 and 75% of wall circumference, depending on location, partial resection with either suture repair or patch may be utilized. Larger tumor involvement of more than 75% vein circumference dictates the need for

segmental resection unless evidence of chronic infrarenal IVC occlusion with adequate collateral formation is present. Primary circumferential repair is preferred if the resection gap is small enough such that the caval ends can be approximated without tension, although most cases require a synthetic interposition graft with the preference of most surgeons being PTFE. Our review demonstrates that an increase in ligation without repair perhaps indicating an increasing willingness to sacrifice the IVC, avoiding risk for pulmonary embolism. Further, evolution of transplant techniques has led to hepatic vein reconstruction likely resulting in the demonstrated increase in autologous vein patching. Transplant literature also

demonstrates IVC reconstructive success using allograft iliac vein from cadaveric donors which has started to infiltrate hepatobiliary practice; however, this is not allowed in the USA under current UNOS guidelines [19–21].

Post-operative patency rates remained high across all three reviews at greater than 95%, morbidity rates have remained stable at approximately 40%, and 30-day mortality has decreased (Table 3). While difficult to draw conclusions due to the population heterogeneity, this may illustrate a progressive understanding of physiology and technology. For, despite the fact that cases have become increasingly complex, morbidity and acute mortality have stayed the same. Conversely, there was a decrease in survival. We hypothesize, particularly from our own anecdotal experience, that this may be due to more liberal criterion and a decrease in selection bias, adopting an intention-to-treat approach inevitably resulting in patients with worse prognoses getting operations. Additionally, the disease heterogeneity between reviews demonstrates more operations for HCC in the last half decade, which can affect survival rates.

This systematic review has many limitations. Due to the rarity of the procedure, this is a selected group of patients based on anatomy and disease biology factors who are candidates for aggressive resection. Therefore, this data is clearly susceptible to selection and recall bias. Further, this cohort of patients has significant disease heterogeneity with HAE, an aggressive form of hepatic hydatid disease, being included as the primary focus was operative technique. Tumor involvement with the IVC is dependent on disease type and, as such, aggregate conclusions must be interpreted very cautiously. Of note, only malignant disease cases were included in cumulative survival estimates. Not every study examined had the documented variables outlined in our results. For instance, only 203 of 350 patients had IVC reconstructive technique described and in calculating overall survival, different studies were included in each of the time periods due to reporting variations, resulting in a higher 5-year than 3-year survival rate. For this reason, tables with each study's individual results were included. This limited our ability to conjecture on mortality and its relationship to IVC replacement, post-operative complications such as hepatic failure, or oncologic pathology. We did exclude studies that did not have separate data for IVC resection cases [30–32]. However, one study was included as it had separate mortality outcomes for IVC resection although did combine IVC resection with hepatic vein resection for morbidity outcomes [40]. Since the majority of these cases were for IVC resection (> 70%), these results were included but must be interpreted cautiously. Finally, the combination of search databases used to perform the systematic review is suboptimal as per the gold standard for systematic reviews due to author access limitations [77].

This systematic review demonstrates a need for standardized reporting of outcomes and establishment of an international registry for appropriate, disease-based, best evidence practice recommendations.

## Conclusion

This systematic review examines the operative approach and management of hepatic IVC resection and reconstruction over the last half decade, with a witnessed evolution in technique demonstrated. There was increased utilization of ex vivo approaches and decreased use of venovenous bypass compared with previously published reviews which may indicate improvements in operative techniques, peri-operative management, and anesthesia. In order to gain evidence for a consensus to be reached on operative and post-operative management, a registry would be beneficial.

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**Authors' contributions** Study conception and design: MBG, DI, JM, EB, PAC, DV. Acquisition of data: MBG, CT, MW, JS, PS, DV. Analysis and interpretation of data: MBG, CT, MW, JS, PS, DV. Drafting of manuscript: MBG, CT, MW, JS, PS. Critical revision of manuscript: MBG, CT, DI, JM, EB, PAC, DV.

## Compliance with ethical standards

**Conflict of interest** The authors declare that they have no conflicts of interest.

**Ethical approval** This article does not contain any studies with human participants or animals performed by any of the authors.

**Code availability** None used.

**Availability of data** Upon request, available.

## Appendix 1

**Table 4** Search terms combined using Boolean logic within column terms combined using “or” statements; “and” statements used to combine terms between columns

Inferior vena cava	Surgery	Hepatic	Disease
Inferior vena cava	Surgery	Liver	Malignancy
IVC	Resection	Hepatic	Oncology
Vein	Procedure	Hepatobiliary	Cancer
Venous	Treatment		Tumor
	Surgical outcomes		Disease

## Appendix 2

**Table 5** Patient and disease characteristics

Study	Year	<i>N</i>	Female (%)	Age	Tumor size (cm)
Ko et al. [39]	2016	8	2 (25)	72 (36–78)	7.5 (5.5–20.0)
Li et al. [46]	2016	13 23 6	5 (38.5) 6 (26.1) 1 (16.7)	50.1 ± 10.5 52.4 ± 11.2 51.7 ± 10.4	
Wen et al. [45]	2016	15	8 (53.3)	38 (16–54)	
Ho et al. [37]	2017	4	3 (75)	51.5 (38–72)	
Kasai et al. [38]	2017	39	7 (17.9)	55 (49–67)	11.0 (7.0–13.0)
Vicente et al. [35]	2017	4	2 (50)	55 (43–63)	
Lee et al. [42]	2018	3	3 (100)	51 (34–54)	
Oldhafer et al. [43]	2018	8	6 (75)	55.5 (49–70)	
Baimas-George et al. [14]	2019	3	3 (100)	41 (36–73)	11.3 (8.8–12.7)
Chen et al. [40]	2019	105	10 (9.5)	51 (48–57)	8.0 (5–11)
Du et al. [44]	2019	5 8	4 (80) 3 (37.5)	30.6 ± 8.3 37.1 ± 11.5	110.5 ± 43.0 161.3 ± 57.1
Shen et al. [36]	2019	45 26	30 (66.7) 17 (60.7)	34.5 (± 9.9) 33.7 (± 10.5)	15.8 ± 2.6 12.0 ± 3.9
Tomimaru et al. [34]	2019	12	4 (33.3)	62 (39–79)	
Matsukuma et al. [41]	2020	16 8	3 (18.8) 2 (25)	66 (60.5–75) 68 (63–73)	7.6 (5.4–12.5) 7.2 (6.3–13.1)

Values reported as No. (%), median (range), or average (± standard deviation)

# Appendix 3

**Table 6** Post-operative results and venous reconstruction outcomes

Study	N	R0 resection	LOS	Anti-thrombotic therapy	Length of anti-thrombotic therapy	IVC thrombosis	IVC Infection	Outflow Stenosis	CD > 3	CD < 3
Ko et al. [39]	8		15 (12–24)			0			0 (0)	3 (37.5)
Li et al. [46]	13	13	19 (10–24)	LMWH in hospital; Coumadin at discharge	90 days	0	2		5	2
Li et al.	23	23	20 (12–30)	LMWH in hospital; Coumadin at discharge	90 days	1	0		10	3
Li et al.	6	6	27 (17–44)	LMWH in hospital; Coumadin at discharge	90 days	1	0		3	1
Wen et al. [45]	15		32.3 (12–60)						3	
Ho et al. [37]	4	4 (100)	21 (13–29)						3	1
Kasai et al. [38]	39	31 (79)							26 (67)	
Vicente et al. [35]	4		13 (11–14)	Ppx heparin	30 days	1 (at 14mos)			2	1
Lee et al. [42]	3		10 (7–14)					1 (*IR balloon dilatation)	0	0
Oldhafer et al. [43]	8		28 (18–54)			0			7	1
Baimas-George et al. [14]	3									1
Chen et al. [40]	105									
Du et al. [44]	5		59.8 ± 23.7	“Rare” after surgery					9	29
Du et al.	8		43.5 ± 28.8	“Rare” after surgery					0	5
Shen et al. [36]	45		19 (15–24.5)	Ppx LMWH	POD2 to discharge	0			1	7
Shen et al.	26		9 (8–12.3)	Ppx LMWH	POD2 to discharge	0		4 (*balloon replacement)	11	10
Tomimaru et al. [34]	12		33.5 (13–164)	Anti-thrombotics given in 8/12 cases		0		0	7	5
Matsukuma et al. [41]	16	10	28 (22–44)						2	
Matsukuma et al.	8	5	33 (22–39)						1	7
									3	2

Values reported as No. (%), median (range), or average (± standard deviation)

LOS length of stay, IVC inferior vena cava, CD Clavien-Dindo complication, Ppx prophylactic dosing, LMWH low molecular weight heparin

\*Treatment for obstruction

## Appendix 3References

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